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IMPROVED PRODUCTION PROCEDURE FOR MANUFACTURING CHROMIUM BRONZE BARS

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A thermal deformation treatment (TDT) method is developed and implemented during production of industrial batches of chromium bronze bars, according to which aging is performed after intermediate billet drawing to a prefinishing diameter, then finishing drawing of an aged billet follows to a final diameter with a drawing factor of 1.10–1.25. Batches of bars treated by this method correspond entirely to all standard document specifications with respect to hardness and longitudinal curvature, and bars have the required marketable condition with smooth, defect-free, shiny surface typical for cold-drawn products.
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Within the group of chromium bronzes there are binary copper-chromium or complex chromium-containing low-alloy copper materials [1]. Strengthening is achieved by quenching and subsequent aging, as a result of which chromium or chromium-containing chemical compounds are precipitated [2]. The bulk of chromium-containing alloys in the overall output of low-alloy copper materials is of the order of 60%; copper-chromium and ternary copper-chromium-zirconium systems are used most extensively, whose production reaches 80% of the total volume of chromium bronze output. Alloys based on these two systems, and also other complexly-alloyed chromium-containing alloys, exhibit a unique combination of properties, and this makes it possible to use the alloys in heat exchange units (molds and other installations), electric resistance welding machines (electrodes, armatures), in electrical engineering, electronics, instrument building, and other branches. Chromium bronzes are dispersion-hardened alloys, and therefore the unique properties achieved by optimizing physico-chemical properties promoting their productive use are only achieved by heat treatment, which is effectively thermal deformation treatment (TDT). (The terms "thermomechanical treatment" (TMT) and "mechanothermal treatment" (MTT), often used in technical publications, should be considered obsolete. A more functional understanding, combining both versions is considered to be TDT [6], for which the existence and duration of time interval between deformation and heat treatment (or in reverse order) is not an obligatory condition.)

Heat treatment (as applied to the group of thermally strengthening alloys is often called "improvement"), as a rule, includes quenching, fixing a supersaturated solution of alloying element in a base, and aging, during which there is decomposition and precipitation of fine particles of the strengthening phase. Only after quenching and subsequent aging is use of chromium bronze more effective, since in other conditions its properties are markedly lower [3, 4].

However, the level of strength properties obtained for semi-finished products, subjected to aging without prior deformation, under conditions of severe operating regimes, is clearly inadequate [3, 4], and in order to satisfy the increasing demands TDT is used, in which between quenching and aging there is cold plastic deformation, having a strong effect on

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structure formation during aging [5]. The level of strength properties together with entirely acceptable electrical conductivity of alloys, given TDT, is markedly higher compared with alloys given aging without prior deformation. The complexity of interaction of a considerable number of factors, affecting chromium bronze properties (chromium content, ingot preparation method, degree of hot and cold deformation during treatment, heating conditions for hardening and cooling method after it, aging regime) complicate the search for production treatment regimes applied to specific manufacturing conditions and specifications for finished object operating properties. In view of this, until recently an optimum solution has not been found for such a complex problem, and the search for optimum production regimes is carried out in relation to user enterprise requirements for semifinished product properties and their production conditions.

One of the most advanced TDT methods [2] involves quenching of hot-worked billet from a specific temperature, cold plastic deformation between quenching and aging in a version of no less than two-fold wire drawing in order to obtain a finished object with a degree of deformation ε = 40–70%, and aging, whose regime is quite stable and in this situation does not have a marked effect on semifinished product properties. Use of a method in [2] with the aim of obtaining an increased hardness level, controlled bar curvature, and high surface quality, is connected with the following disadvantages.

The grade used most widely for bronze is BrKh1 providing alloying with chromium in an amount of 0.4–1.2%, although the required hardness level for alloy with this chromium content is close to the lower limit of the range after TDT by the method in [2], and is almost unachievable. For example, at one of the nonferrous metal treatment plants with output of industrial batches of bars 9–13 mm in diameter for a significant part of the production the Rockwell hardness value (scale B) appears to be below that established by the standard documentation.

Of many factors acting on actual manufacturing conditions, it is possible to separate both readily controllable (drawing factor during hot pressing of a billet in horizontal hydraulic presses and during drawing between quenching and aging; quenching and aging regimes, etc.), and almost uncontrollable (melting in furnaces of a specific type, i.e., since there are simply no other furnaces; use of casting and its regimes, component alloying content limit, etc.). It is also impossible to exclude purely production subjective factors, complicating a situation: difficulty of striking a precise alloy composition, speed and accuracy of melt rapid analysis, complexity of controlling some melting and casting parameters within established ranges, etc. Under conditions of such a number of actively variable factors the possibility of optimizing technology is almost exhausted if they are only directed at the TDT method [2]. Some disadvantages are listed below for existing technology, which it was intended to overcome in developing new approaches to preparing high quality product.

1. Instability of results in the area of bar Rockwell (scale B) hardness, i.e., not less than 75 units.

2. Worsening of such an important index as longitudinal curvature of bars cut into measured lengths as a result of unavoidable thermal stresses, generating so-called thermal distortions during heating and exposure of objects for 2–4 h during aging, completing the treatment cycle.

3. Apart from mechanical property requirements for semifinished products, many users lay down very rigid requirements for the external appearance of bars. In particular, according to the interstate "Technical specifications for round section bar of alloy grade S18200" (i.e., bronze BrKh1), bar surface should be smooth and clean without contamination making examination difficult. This external appearance of bars is impossible to achieve using the method in [2], since the finishing operation with this production scheme is aging. During 2–4 h of heating and soaking in a furnace, even with the use of protective atmospheres or a vacuum, almost excluding oxidation, bar surface cannot have the correct finished appeaerance, and it looks matte. In the absence of a protective atmosphere, which is often widespread in existing workshops, a pickling operation is prescribed, after which the external appearance of bars also does not correspond to the high specifications; in addition, pickling prolongs the production cycle, increases production outlay, and worsens an ecological situation.

With the aim of avoiding the disadvantages listed above, the authors have proposed, proven, and accomplished a method in practice [8] according to which the aging operation is carried out after wire drawing of an intermediate billet to prefinishing dimensions, then finishing wire drawing is carried out for an aged billet to final dimensions with a drawing factor established in the range 1.10–1.25.

For comparative analysis of the qualitative level and quantitative characteristics of bars, prepared by the regime in [2] and developed by the method in [8], tests were performed and industrial test batches of improved bars were produced of bronze grade BrKh1 12.7 and 12.25 mm in diameter. The results of analysis are given below.

1. According to [2], an original hot-pressed wire-bar billet 90 mm in diameter was quenched and drawn in a VSG 1/720 mill by a route, mm: 19.0 → 15.1 → scalping to diameter 14.9 → 13.5; then finish drawing to diameter 12.7 and 12.25 mm in an automated Shumag line with simultaneous cutting of bars into measured lengths and straightening; then aging, pickling, washing, and drying. The overall drawing factor and degree of deformation during drawing was:

• for bar diameter 12.7 mm,

$$\lambda_\Sigma = \left(\frac{19}{15.1}\right)^2 \left(\frac{14.9}{13.5}\right)^2 \left(\frac{13.5}{12.7}\right)^2 = 1.58 \cdot 1.22 \cdot 1.13 = 2.18;$$

$$\varepsilon_\Sigma = \ln\lambda_\Sigma = 0.55;$$

• for bar diameter 12.25 mm, $\lambda_\Sigma = 2.35$ and $\varepsilon_\Sigma = 0.78$, which corresponds to values of ε_Σ in method [2].

In testing finished bars treated by the regime in [2], it was revealed that up to 80–90% of the product does not meet the standard specifications for hardness, and about 30% of bars have deviations from the standard with respect to longitudinal curvature. After performing operations connected with cleaning pickling, semifinished product did not have a marketable appearance, and in fact: there was a rough matte surface in areas, colored in the form of a deposit of secondary copper from the picking solution, and there were diffuse fine defects in the form of pock marks.

2. Use of the production regulations according to [8], as the output of industrial test batches showed, made it possible to obtains bars of stably guaranteed quality, entirely meeting all specifications of the standard document, including for hardness, longitudinal curvature, and also marketable appearance. Bars have a defect-free shiny surface typical for cold-drawn objects.

With breeching of the limits for the recommended range of drawing factor $\lambda = 1.10–1.25$ in the finishing drawing pass the following unfavorable phenomena may arise:

• with $\lambda < 1.10$, the guaranteed hardness value of ≥75 HRB is not achieved; nonuniform deformation over the bar cross section, since it is well known that use of extremely small reduction (≤5–6%) produces increased strain inhomogeneity through a bar cross section, and therefore according to the Gubkin equation [7] they acquire the minimum permissible relationship

$$\frac{d_1}{d_0} = \left(\frac{5 + \cos\alpha}{\sin\alpha} - 1\right) \Big/ \left(\frac{5 + \cos\alpha}{\sin\alpha} + 1\right),$$

where d_1 and d_0 are correspondingly final and initial bar diameter; α is semi-angle of a deformation zone of a drawing channel;

• with $\lambda > 1.25$, drawing stability is worse for metal, given aging and for this reason reduced ductility, which increases the probability of breaks; in addition, there may be an increase above the standard longitudinal curvature for bars as a result of introduction of residual tensile stresses of a considerable level into its surface layers.

Conclusion. Implementation of the developed and effectively used improved method of thermal deformation treatment during output of industrial batches of bars of chromium bronze has provided an increase in product quality: guaranteed achievement of Rockwell hardness values (scale B), observation of specifications for longitudinal curvature, and preparation of a high quality external appearance of semifinished product.

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